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UPSCALE OF THE TWO-STAGE GASIFICATION PROCESS

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ABSTRACT: The two-stage biomass gasification process was developed at the Technical University of Denmark (DTU). The process is a unique biomass gasification process: It combine stable unmanned operation, high coldgas efficiency (above 95%) and low tar content in the gas ($<5 \text{ mg/Nm}^3$), [1]. With use of modern gas engines the electric efficiency will exceed 35% and the total efficiency will exceed 100%.

COWI and DTU have a long tradition of corporation within development of biomass gasification, especially together with various industrial partners [2]. In order to mature and demonstrate the two-stage technology COWI and DTU corporate regarding upscale and further process development.

In order to upscale to plants of 1MWe and above the two-stage gasification process is modified [3]. The upscaleable concept, which both offer low tar and high efficiency can be designed as both moving (fixed) beds and fluidbeds. The first two industrial partners are now involved in the upscale and further development of the two-stage technology. Weiss A/S regarding the moving bed and Babcock&Wilcox Voelund regarding fluid bed technology.

1. PURPOSE OF THE WORK

There is a large market for medium and large-scale biomass gasification combined heat-and power plants (CHP). The existing atmospheric pressure gasification technologies for medium and large-scale gasification are complicated in order to reduce the tar-content in the produced gas and/or have low electrical and overall efficiencies.

In the two-stage gasification process, the pyrolysis and the gasification process are separated into two different zones. In between the pyrolysis and the gasification zones, the volatiles from the pyrolysis are partially oxidised. Hereby, most of the tars are decomposed into gas [4].

To enable high energy efficiency, the thermal energy in the gasification gas and the exhaust gas is being used for drying, air preheating and for pyrolysis.

The two stage gasification process has successfully demonstrated [1] that the process offers

- Low tar content in gas ($<5 \text{ mg/Nm}^3$)
- Stable unmanned operation
- High coldgas efficiency ($>95\%$)
- Low environmental impact (clean condensate, high carbon conversion)

In Figure 1 is seen the VIKING two-stage gasifier. This was established in 2002 and the gasifier had during 2003 more than 2000 hours of operation (including gas engine). The gasifier was operated for 2-3 weeks at a time and was inspected between the tests. The materials look good and further experience with operation is carried out during 2004. [8].



Figure 1. VIKING two-stage gasifier at DTU

The process verification and documentation has been performed in small scale, and in order to manufacture economical attractive plants the process is now being upscaled.

2. UPSCALE OF THE TWO-STAGE GASIFICATION PROCESS

The two-stage gasification process will be somewhat modified in order to upscale to CHP plants of 1MWe and above. The upscaled gasification concept combines the advantages of

- Stage divided gasification
- drying with superheated steam
- pyrolysis with superheated steam
- Partial oxidation
- gasification with steam.

2.1 Drying with superheated steam

Drying with superheated steam involves one or more external heatsource(s) (fluegas, hot oil, steam..) that are heat exchanged with water vapour evaporated from the product. The superheated steam is led back to the dryer, and is then the drying medium in the dryer (see Figure 2)

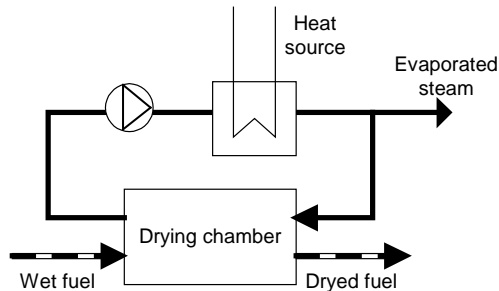


Figure 2 Principle of drying with superheated steam.

Drying with superheated steam is a well known technology, and it offers a number of advantages:

- *Environment friendly drying:* (no contamination of condensate)
- *No Fire hazards.*
- *No loss of product.*
- *Improved drying rate.*

Superheated steam dryers have been developed to dry from 0,5 to 50 tons vapour pr. hour. This corresponds to 2,5 –250 MW thermal input if the fuel is woodchips with a moisture content of 50%

2.2 Pyrolysis with superheated steam

Pyrolysis with superheated steam is a well-known technology, used in kilns to make activated charcoal.

Since the produced steam from the dryer is used as the heat carrier for the pyrolysis process, the two-stage gasification process is applicable for fuels that are relatively wet. Fuels with moist content up to 60% can be gasified with high efficiencies. This makes woodchips ideal for this process, which however also will be able to use other biomass, sludge and selected solid waste's.

When dry fuels are used, other heat sources than the steam from the fuel must be added to the pyrolysis reactor:

- Hot product gas from the gasifier.
- Other heat sources, e.g. returned charcoal, bed material or fluegas from engine/gasturbine
- Additional water can be added e.g. evaporated condensate from gas cooling or a condensing unit

2.3 Gasification with steam as gasification agent

It is well known, that gasification with steam as gasification agent result in higher reaction rates than gasification with CO₂ [5]. If steam is the primary gasification agent instead of CO₂ the temperature in the gasifier can therefore be lowered. There are several other advantages related to steam gasification.

- *Lower temperature in partial oxidation zone:* The temperature in the partial oxidation zone decreases about 200°C when gasifying with steam compared to gasification of dry fuels. These observations are confirmed by mathematical modelling [6].
- *Lower soot production:* The amount of soot particles are reduced considerably when gasifying with steam. This is partly due to lower maximum temperatures and partly due to higher concentration of OH radicals which reduce the soot production.
- *Lower emissions after engine:* The gascomposition is different when steam is added as a gasification agent. The H₂ content is increased and the CO content is lowered. The results in a faster combustion and lower emissions of CO and NO_x.

3. ADVANTAGES OF THE UPSCALED TWO-STAGE GASIFICATION PROCESS

The upscaled two-stage gasification concept can be designed in different ways.

Common advantages for the gasification plants will be:

1. Low tar content in produced gas.
2. High cold gas efficiency
3. The gas cleaning will be relatively simple and robust.
4. Stable process
5. Clean fluegas to be used for district heat in condensing mode without cleaning of condensate.
6. No fire hazards in dryer.
7. Low maximum temperatures in gasifier.
8. Low soot production.
9. Low emissions from combustor
10. Well suited for fuels with moist content of 40-60%.

4. UP SCALE OF MOVING BED DESIGN

In a medium size (3-10 MW thermal) two-stage gasification plant, the pyrolysis and the gasification reactor can be of a moving bed type, as the well known horizontal screw pyrolysis unit and a vertical charbed.

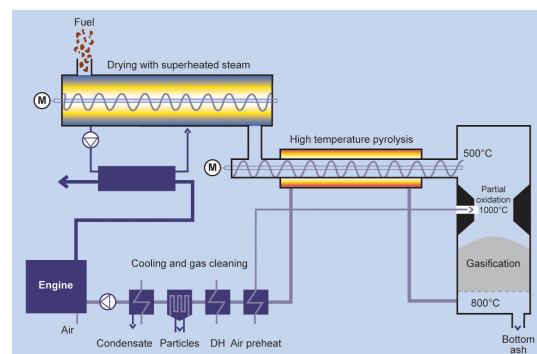


Figure 3 Schematic layout of a two-stage gasification plant with drying, pyrolysis and the gasification reactors of moving bed type.

The design shown in Figure 3 is based on the well known fixed bed two-stage gasifier. The pyrolysis reactor is in this design heated with two heatsources:

- direct heated by hot steam and
 - indirectly heated by hot product gas from the gasifier.
- Hereby the retention time of the biomass in the reactor can be reduced from about ½-1 hour to a few minutes. The size of the pyrolysis reactor can therefore be reduced considerable.

Model calculations of a CHP plant with gas engines as suggested in Figure 3 shows an electrical efficiency of 35% and a total efficiency of 100%, when modern gas engines are used.

A 600 kWth/200kWe two-stage gasification plant will be established in 2004/2005 in corporation between biomass boiler manufacturer Weiss A/S, DTU and COWI, with economic support from ELKRAFT SYSTEM (PSO) funds for R&D in power production.

5. FLUID BED DESIGN

The pyrolysis and gasification reactors can also be designed as fluid beds. Hereby the two-stage gasification process can be scaled up to large applications.

This gasification concept is named Low-Tar BIG (Biomass Integrated Gasification). The development of this process is done in corporation with Babcock&Wilcox Voelund.

The "Low-Tar BIG" concept is based on separate pyrolysis and gasification units. The volatile gases from the pyrolysis (containing tar) are partially oxidised in a separate chamber, and hereby the tar content is dramatically reduced. Thus, the investment, and running cost of a gas cleaning system can be reduced, and the reliability can be increased.

Both pyrolysis and gasification chamber are bubbling fluid beds, fluidised with steam. For moist fuels, the gasifier can be integrated with a steam drying process, where the produced steam is used in the pyrolysis/gasification chamber.

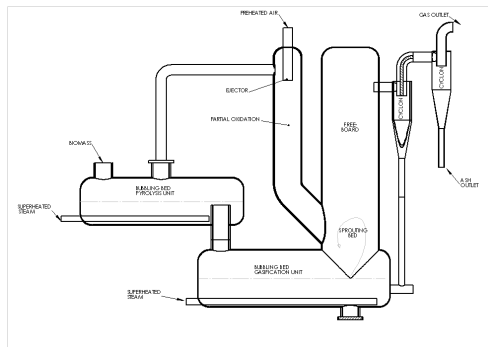


Figure 4: Schematic layout of 10-50MWth Low-Tar BIG gasifier

In this paper, mathematical models and results from initial tests of a laboratory Low-Tar BIG gasifier are presented. Two types of mathematical models are presented:

- System studies: Gas engine, Simple cycle gas turbine, Recuperated gas turbine and Integrated Gasification and Combined Cycle (IGCC).
- A thermodynamic Low-Tar BIG model. This model is based on mass and heat balance between four reactors: Pyrolysis, partial oxidation, gasification, gas-solid mixer.

The main results from the system studies are presented in this paper. For more details, and results of the thermodynamic Low-Tar BIG model please refer to [7].

5.1 System studies.

Thermodynamic models of the Low-Tar BIG gasifier operating in the following systems has been investigated:

- Gas engine
- Gas turbine (Simple Cycle)
- Gas turbine (Recuperated Cycle)
- IGCC

For all the systems, the gasification system is integrated with a steam dryer. The most important parameters for the models are:

- 50% moist in the fuel
- Biomass is dried with superheated steam to 10% moist.
- Gasification at atmospheric pressure.
- Steam is used as the 'agent' for both the pyrolysis and the gasification processes.
- The air is preheated for the partial oxidation
- Condensing and cooling of syn- and flue gas by means of district heating (45°C).

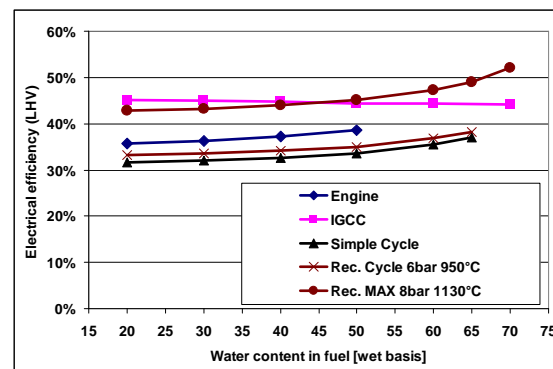


Figure 5: The electrical efficiency as a function of moist content in the fuel

In Figure 5, the electric efficiency of five different plants are shown when the moist content of the fuel is changed. The plants are (according to the legend in the right side):

- Gas engine with electrical efficiency of 40%
- IGCC plant with gas turbine at 20 bar and combustion at 1150°C
- Simple cycle gas turbine at 20 bar and combustion at 1150°C

- Recuperated gas turbine at 6 bar and combustion at 950°C
- Optimal recuperated gas turbine at 8 bar and combustion at 1130°C.

5.3 Results with laboratory gasifier

A 100kWth laboratory plant has been built, and process stability, low tar content and mass and energy balance have been verified.

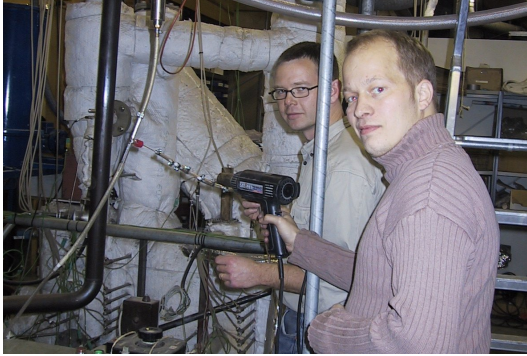


Figure 6: Tar measurements are carried out during test of 100 kW Laboratory gasifier in november 2003.

The tarcontent in the raw gas in the initial tests was below 1 g/Nm³. After a simple filtration the tarcontent was below 25 mg/Nm³. These results are rather unique for a fluid bed biomass gasification process. A test series is planned for 2004 aiming at lowering the the tar-content further.

Below in figure 7-9 is seen the temperatures in the pyrolysis, partial oxidation and gasification reactor during a test in november 2003.

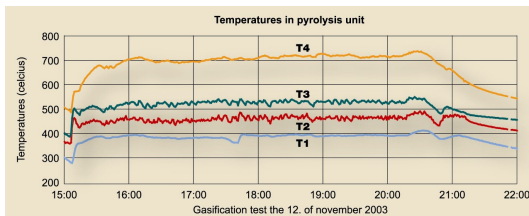


Figure 7: Temperatures in pyrolysis reactor

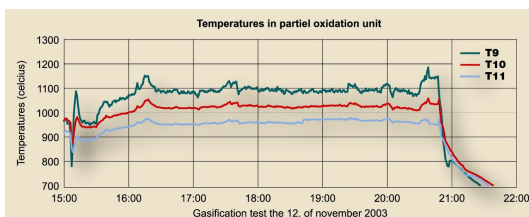


Figure 8: Temperatures in partial oxidation reactor

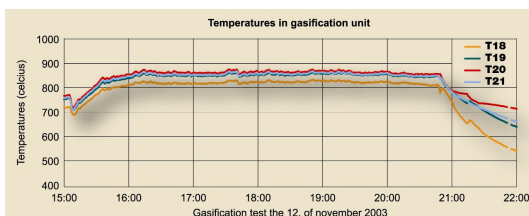


Figure 9: Temperatures in gasification reactor

CONCLUSIONS

The unique features: stable unmanned operation, high coldgas efficiency (above 95%) and low tar content in the gas (<5 mg/Nm³) of the two-stage biomass gasification process can be achieved in upscaled plants, which will result in a economically attractive technology.

The upscale of the moving/fixed bed is starting with the establishment of a 600kWth/200kWe pilot plant in corporation with boilermanufacturer Weiss A/S.

The development of a fluidbed two-stage gasifier has started. A 100 kW laboratory gasifier was built in corporation with Babcock&Wilcox Voelund and the initial results are very positive.

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